

## NOAA Coral Reef Watch

### 2016 Annual Summaries of Thermal Conditions Related to Coral Bleaching for the U.S. Coral Reef Jurisdictions

#### Executive Summary

During 2016, the [warmest year on record globally](#) (for a third year in a row), the [third confirmed global coral bleaching event](#) continued and intensified. Sustained anomalously high ocean temperatures continued causing widespread, documented coral bleaching in the Pacific, Indian, and Atlantic Oceans. This global event began in the North Pacific Ocean in June 2014 and expanded to the South Pacific, Indian, and Atlantic Oceans in 2015. As of early 2017, it is still ongoing. The event has been associated with an extensive warm “Blob” in the northeastern Pacific Ocean lasting from late 2013 into 2015, a partially-formed 2014-15 El Niño, and a record-strength 2015-16 El Niño. NOAA Coral Reef Watch’s (CRW) near-real-time satellite monitoring (especially via its [daily global 5km satellite coral bleaching heat stress products](#)) and modeled [Four-Month Coral Bleaching Heat Stress Outlook](#) triggered a multi-year, global-scale, *in situ* coral bleaching survey effort. This has led to the timely collection of global reef condition data from before, during, and after the rolling global event hit regional coral reefs sequentially and/or repeatedly. NOAA’s declaration of the third global bleaching event (after the 1997-1998 and 2010 global events) stemmed from CRW’s global satellite monitoring and bleaching outlook and subsequent confirmation by field observations from all three ocean basins.

As noted in 2015, U.S. coral reefs have been hit disproportionately hard in this global bleaching event. For the third year in a row, U.S. coral reefs experienced bleaching over a wide area. Data analysis based on CRW’s daily global 5km satellite monitoring showed that during 2014-2016, 100% of U.S. coral reef areas experienced bleaching heat stress at CRW’s defined heat stress levels of Bleaching Warning, Alert Level 1, or Alert Level 2. Alert Level 2 heat stress (associated with widespread coral bleaching and mortality) was experienced by about 50% of U.S. coral reef areas, and Alert Level 1 heat stress (associated with significant bleaching) was experienced by an additional 29% of U.S. reefs. Meanwhile, globally nearly all coral reef areas experienced heat stress at Bleaching Warning or above, with about 29% experiencing Alert Level 2 conditions and an additional 47% experiencing Alert Level 1.

While a version of CRW’s [50km satellite products](#) (that are based on the new operational 50km Sea Surface Temperature (SST) data stream derived from the NOAA/National Environmental Satellite, Data, and Information Service’s (NESDIS’) daily 5km Geostationary-Polar-orbiting (Geo-Polar) Blended Night-only SST Analysis; Liu *et al.*, 2013) continued to operate throughout 2016, this summary report for the U.S. coral reef jurisdictions focuses predominantly on thermal conditions monitored by CRW’s next-generation [daily global 5km satellite coral bleaching heat stress monitoring products](#) (Liu *et al.*, 2014). Now in version 3 (v3), the 5km satellite products are featured on the CRW website as the core of its decision support system for coral bleaching alerts. Similar to the prior 50km products, the 5km global satellite products include SST, SST Anomaly, Coral Bleaching HotSpot, Degree Heating Week (DHW), a 7-day maximum Bleaching Alert Area, and a 7-day SST Trend product. The 5km products provide much higher spatial and temporal

resolutions and more data per satellite pixel than CRW's heritage 50km monitoring, and allows monitoring of thermal conditions worldwide at or near reef scales. The v3 suite, which uses a significantly improved climatology, was introduced in May 2017 but includes reprocessing for earlier years. The new climatology was derived from a combination of a recently reprocessed NOAA/NESDIS daily global 5km Geo-Polar Blended Night-only SST Analysis from 2002-2015 (the result of a multi-year effort), and the 1985-2007 daily global 5km SST reanalysis, produced by the United Kingdom Met Office, on the Operational SST and Sea Ice Analysis (OSTIA) system. CRW's [5km Regional Virtual Stations/Bleaching Heat Stress Gauges](#) and its new, automated [5km Satellite Bleaching Alert Email System](#) (released in October 2016 and now based on the v3 global products), as well as CRW's [Four-Month Coral Bleaching Heat Stress Outlook](#) (v4) also guided the analyses discussed in this report.

As mentioned in prior years' thermal conditions reports for the U.S. jurisdictions, CRW's 5km and 50km satellite products, especially the Virtual Stations products, may differ in their interpretations of the onset, duration, and severity of heat stress within a jurisdiction. Discrepancy between the two product suites is expected as different SST analyses and climatologies are used, and higher-resolution products, although applying the same algorithm as the heritage 50km products, may require adjusted thresholds. With the generally higher quality SST analysis and reprocessed data used in the 5km monitoring, along with increased spatial and temporal resolutions, the overall accuracy of the 5km products is expected to be higher. However, as CRW continues the analysis of its 5km global and regional products, we recommend that resource managers continue to consult both the 5km and 50km product suites, especially both Virtual Stations products, to best understand coral reef environmental conditions in near-real-time in their jurisdictions. In some cases, further high-quality *in situ* observations will be needed to qualitatively and quantitatively evaluate CRW's satellite-based products. We look forward to utilizing *in situ* SST monitoring and bleaching observations from the NOAA Coral Reef Conservation Program's National Coral Reef Monitoring Program to assist with this evaluation.

## ATLANTIC OCEAN

### Florida:

After record high heat stress in 2014 and 2015, on May 24, 2016, CRW's Four-Month Coral Bleaching Heat Stress Outlook (Figure 1) predicted that Alert Level 1 heat stress would develop in the Florida Keys as of early September. On May 31 and June 14, CRW's 5km satellite monitoring detected the development of heat stress in the Florida region and issued a Bleaching Watch for the 5km Regional Virtual Stations for the Florida Keys and Southeast Florida (Figure 2), respectively. (Note that the 5km Regional Virtual Stations are based on data from tens, hundreds, or even thousands of individual 5km data grids.) Over the next few months, the heat stress level at both 5km Stations fluctuated between Bleaching Watch and Bleaching Warning conditions (Figure 3). Then, from August 20-September 1 and again from September 18-October 1, 2016, CRW detected Alert Level 1 heat stress (associated with significant bleaching) in the Florida Keys (Figure 3); both Bleaching Watch and Bleaching Warning conditions, but no higher stress, were present in Southeast Florida during those periods. Cooler waters then arrived in the region, and a Bleaching Watch was issued for both Florida 5km Regional Virtual Stations. No Stress has been maintained since mid-October 2016, as the region moved out of its bleaching season.

2016 May 24 NOAA 60% Probability Coral Bleaching Thermal Stress for Jun–Sep 2016  
Experimental, v3.0, CFSv2–based, 28–member Ensemble Forecast

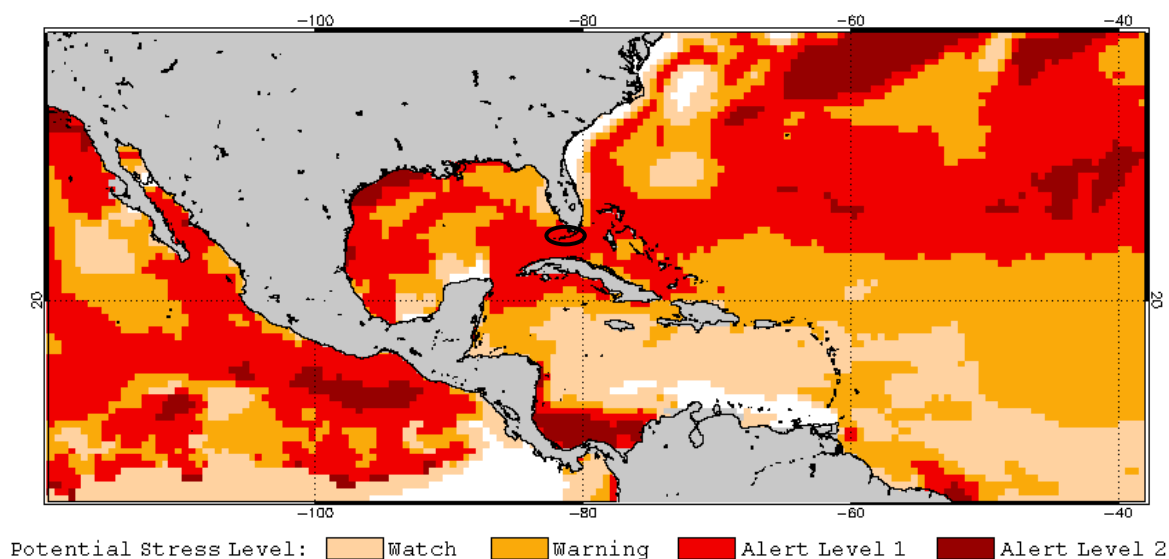


Figure 1. Map of potential coral bleaching heat stress (60% probability) in the Caribbean for June–September 2016 from NOAA CRW’s Four-Month Coral Bleaching Heat Stress Outlook (version 3) issued on May 24, 2016, based on NOAA’s Climate Forecast System v2 SST predictions. The Florida Keys is circled in black.



Figure 2. CRW’s 5km Regional Virtual Stations for the Florida Keys and Southeast Florida.

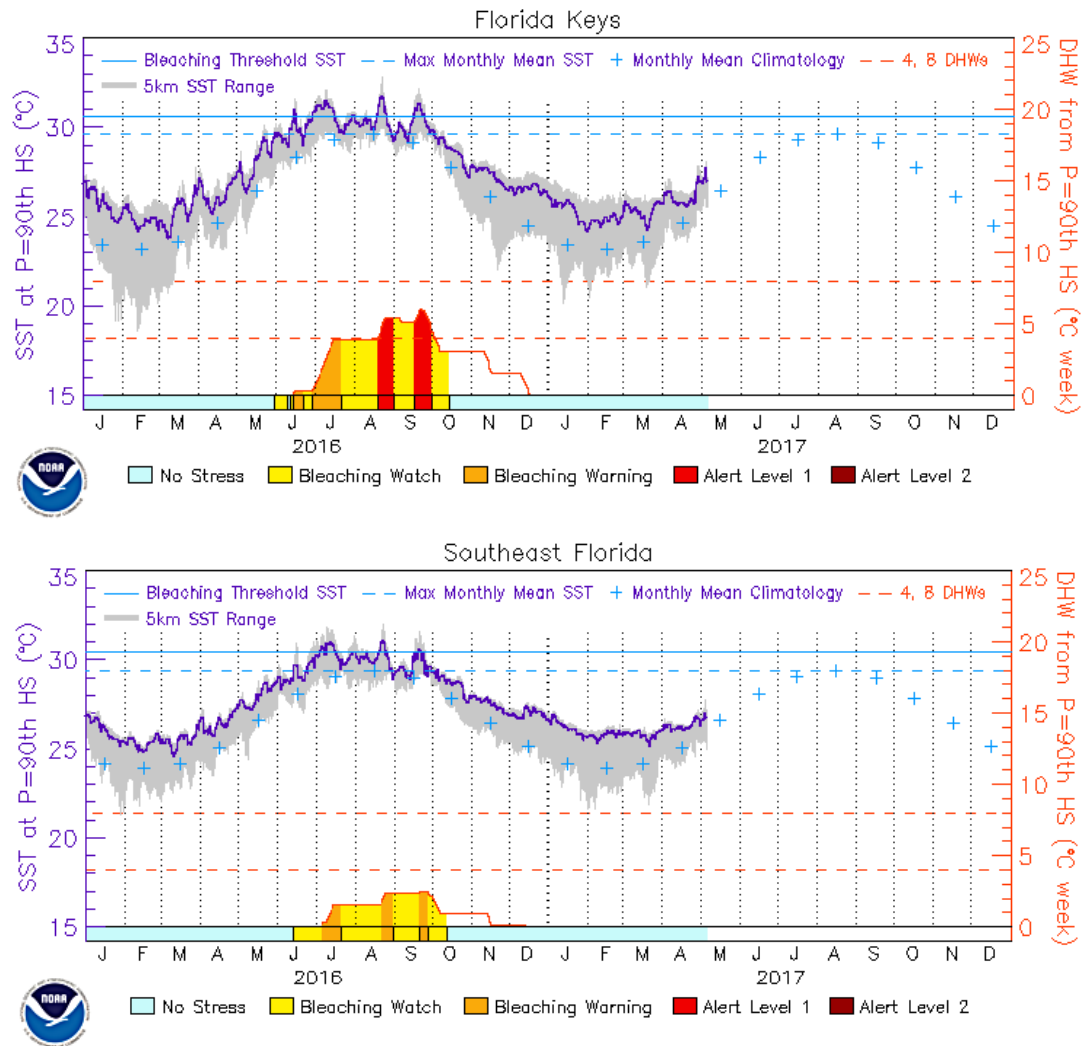


Figure 3. Two-year (January 1, 2016-present) time-series graph for CRW's 5km Regional Virtual Stations for the Florida Keys (top panel) and Southeast Florida (bottom panel). In each graph, the Station's representative (not mean or median) SST value (purple curve) is shown in the center of graph and read using the vertical axis on the left; the Station's 5km Degree Heating Week (DHW) value (red curve) is shown in the bottom portion of the graph and read using the vertical axis on the right; and the Station's Bleaching Alert Heat Stress Levels for the period in question are colored along the horizontal axis, under the DHW curve, and read using the color legend. Note the purple curve denotes the SST at the pixels at the highest 10% of the pixels (90<sup>th</sup> percentile) within the Station each day, and the grey shading around the SST value (purple curve) on the graph identifies the daily range (minimum and maximum values) of 5km SST at each Regional Virtual Station. This provides context on the extent of the daily SST variability at the Station. For Regional Virtual Stations in dynamic oceanographic regions or of larger spatial extent, the range between the minimum and maximum SST each day is expected to be greater. A detailed description of the time series graphs can be found at: <https://coralreefwatch.noaa.gov/vs/description.php>.

CRW's 50km satellite monitoring was slightly more conservative than the 5km products in its estimates of the level of bleaching heat stress throughout Florida in summer and autumn 2016, but not the timing of the heat stress development, which matched the 5km satellite monitoring well. Note that CRW's 50km Virtual Stations are based on data from a single data grid, which contains 100 5km grids, and are usually located further offshore from where 5km products can provide valid

monitoring. CRW's 50km Virtual Stations product (Figure 4) identified the accumulation of DHWs and the onset of a Bleaching Warning as early as June 30 in the Gulf Sloughsway and July 4 in the SW FL Shelf Inshore (Figure 5). Degree Heating Weeks also began accumulating as of August 22, 2016 at the Biscayne and Broward 50km Virtual Stations. However, per CRW's 50km satellite monitoring, Alert Level 1 heat stress never materialized in any of these coral reef areas, or throughout the rest of Florida, during summer and early autumn 2016.

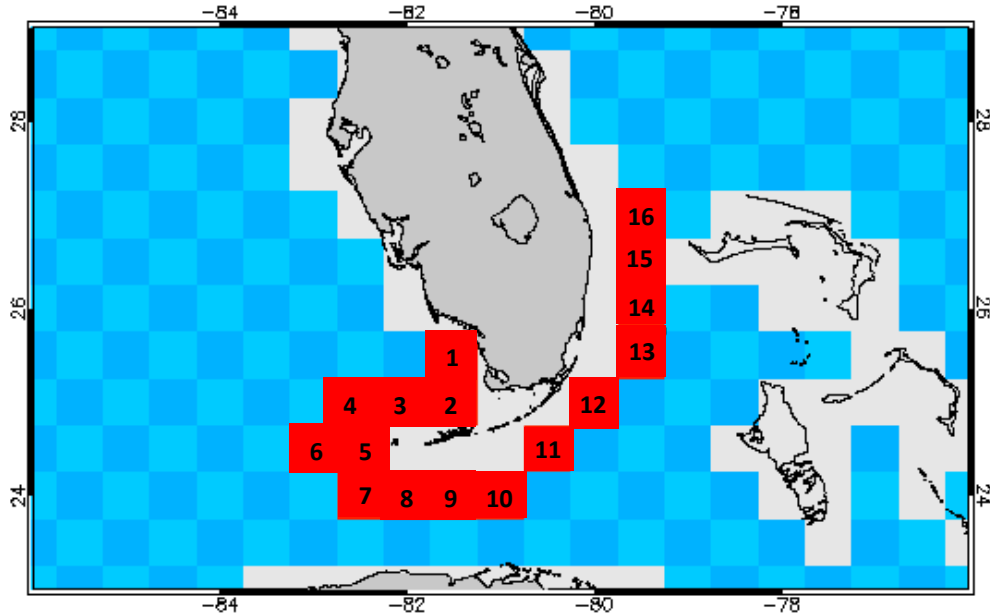


Figure 4. CRW's 50km Virtual Stations (red satellite pixel squares) for the Florida region. Numbered 50km Virtual Stations, which overlap CRW's two 5km Regional Virtual Stations for Florida (Florida Keys and Southeast Florida), include: (1) SW FL Shelf Inshore, (2) Gulf Sloughsway, (3) Gulf SW FL Shelf, (4) SW FL Shelf Offshore, (5) Rebecca Shoal, (6) Dry Tortugas, (7) Marquesas Offshore, (8) Lower Keys-Marquesas, (9) Lower Keys, (10) Middle Keys Offshore, (11) Middle Keys, (12) Upper Keys, (13) Biscayne, (14) Broward, (15) Palm Beach, and (16) Martin. Pixels in light gray are land-mask pixels where no data are provided.

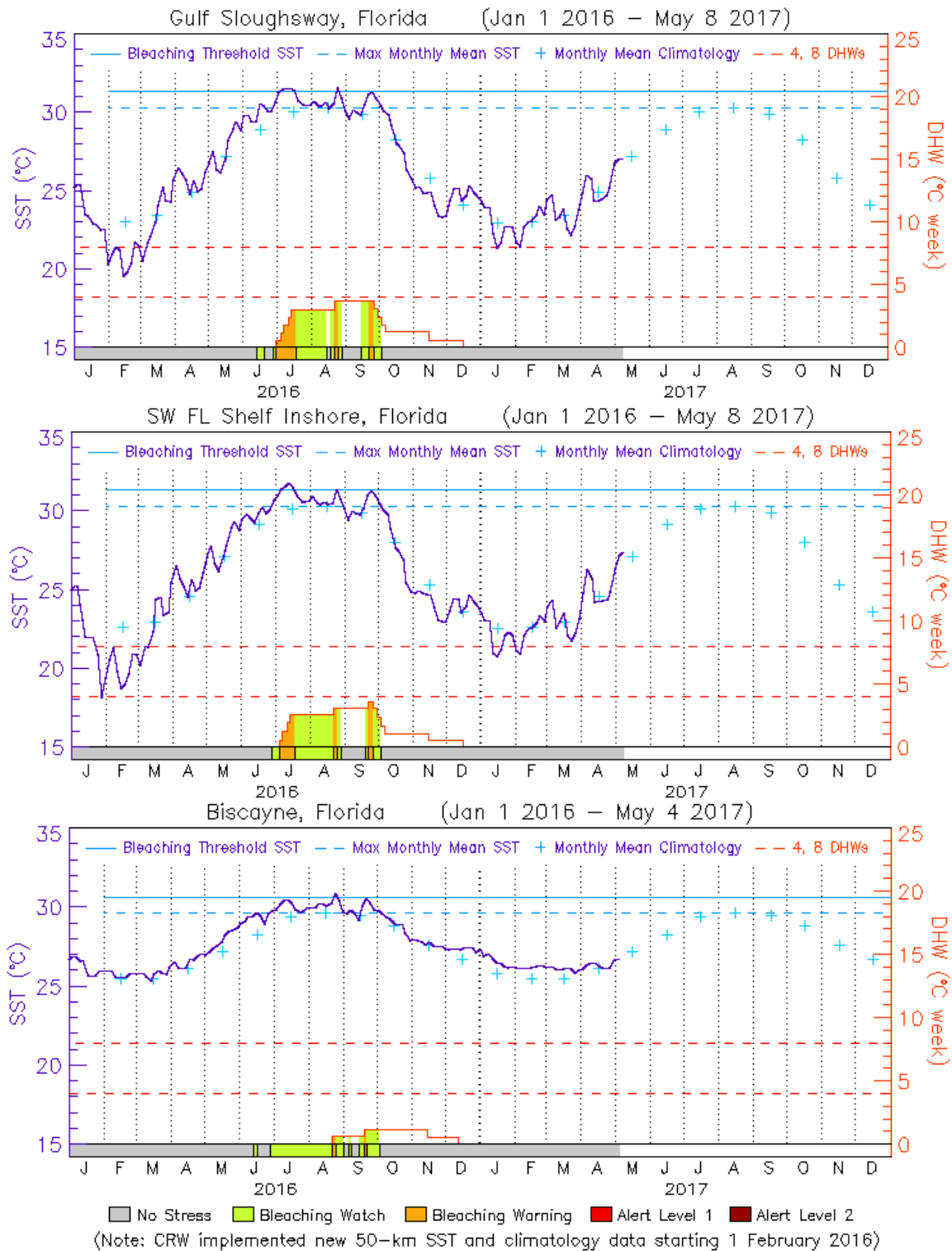


Figure 5. Two-year (January 1, 2016-present) time-series graph for CRW's 50km Virtual Stations at Gulf Sloughsway (top panel), SW FL Shelf Inshore (middle panel), and Biscayne, Florida (bottom panel). See the Figure 3 caption for how to read the graph. Note that climatologies are not plotted for January 2016 due to the implementation of a new SST dataset and climatologies on February 1, 2016.



While some moderate bleaching was reported by local coral reef management partners, no major bleaching was reported on Florida coral reefs during summer and early autumn 2016. This aligns more closely with CRW's heritage 50km satellite coral bleaching monitoring than its 5km satellite products, underscoring the continued importance of CRW's heritage 50km satellite monitoring in addition its high-resolution satellite monitoring. However, it could also represent a real change in the response of Florida corals to heat stress as the more sensitive genotypes may have died in earlier stress events. Multiple FRRP partners reported severe coral disease outbreaks and coral mortality along the entire Florida reef tract, including approximately 95% mortality of *Dendrogyra cylindrus*

#### Flower Garden Banks National Marine Sanctuary:

Based on its 5km satellite monitoring and Four-Month Coral Bleaching Heat Stress Outlook, CRW issued a Bleaching Watch for the Flower Garden Banks National Marine Sanctuary (FGBNMS) in the Gulf of Mexico on June 16 and a Bleaching Warning on June 27, 2016 (Figure 6). The bleaching heat stress level further elevated to Alert Level 1 from July 25-August 19 and to Alert Level 2 (associated with widespread coral bleaching and significant mortality) from August 25-September 19, before Bleaching Watch conditions returned and remained until October 7, 2016 (Figure 6).

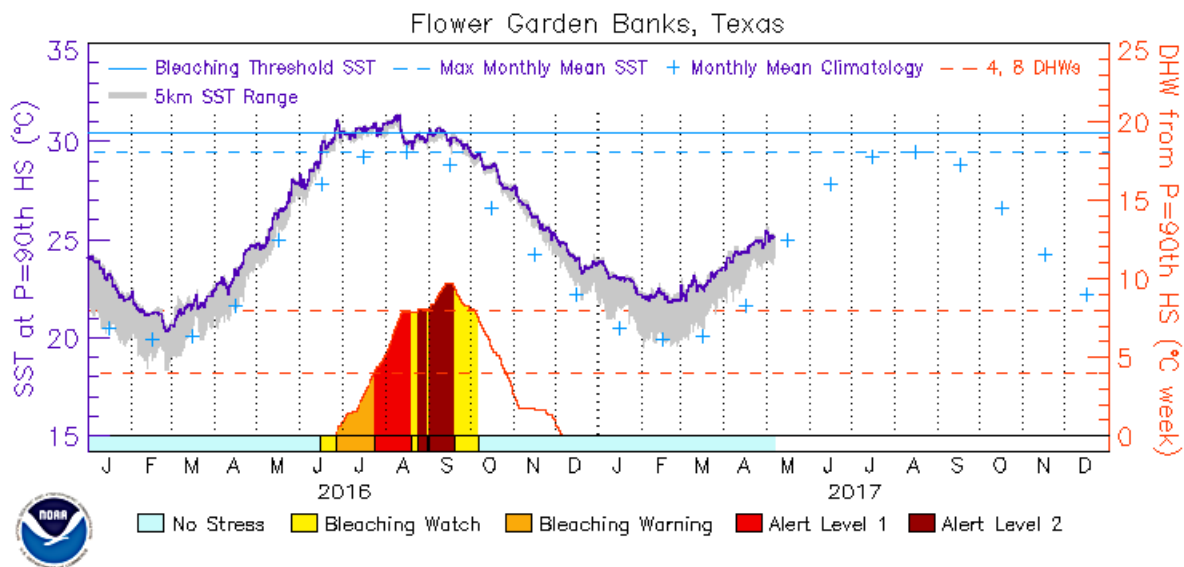


Figure 6. Two-year (January 1, 2016-present) time-series graph for CRW's 5km Regional Virtual Station for the Flower Garden Banks National Marine Sanctuary. See the Figure 3 caption for how to read the graph.

CRW's 50km satellite monitoring indicated that a Bleaching Warning was present as of July 18 and elevated to Alert Level 1 heat stress in the FGBNMS from August 8-11, 2016 only. Per CRW's 50km DHW products,  $DHW \geq 4$  remained in the FGBNMS until October 10, 2016 but Alert Level 1 conditions did not return nor elevate to Alert Level 2 stress (Figure 7).

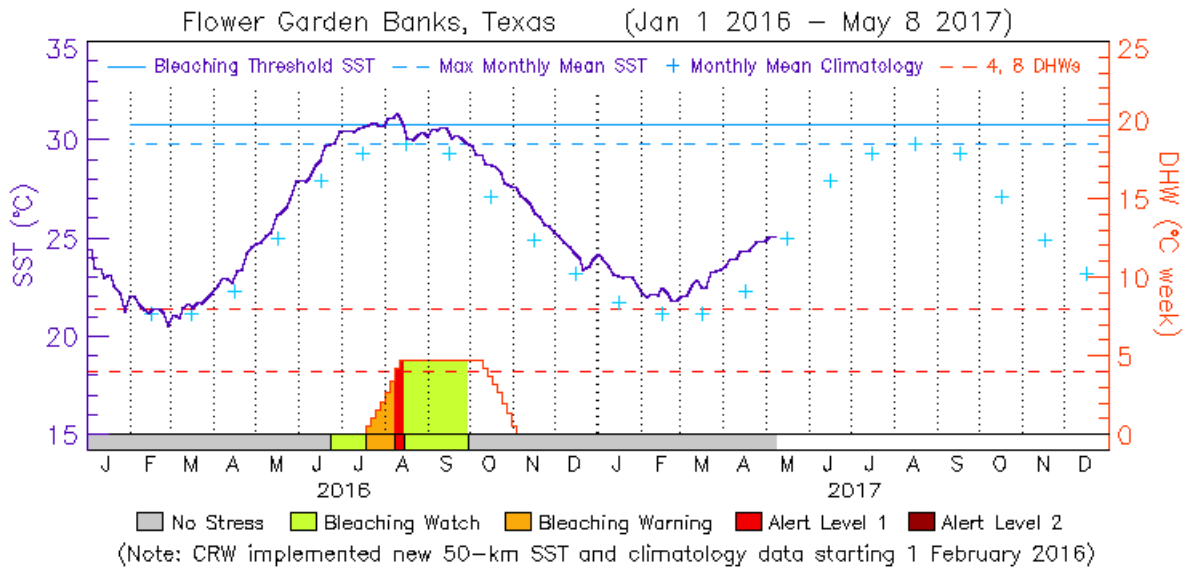


Figure 7. Two-year (January 1, 2016-present) time-series graph for CRW's 50km Virtual Station for the Flower Garden Banks National Marine Sanctuary. See the Figure 3 caption for how to read the graph.

A mass mortality event, of unknown cause, of corals and other invertebrates in the East Flower Garden Bank of the FGBNMS occurred in July 2016. CRW's Four-Month Bleaching Outlook did not predict heat stress for the time period and CRW's 5km satellite products only showed appearance of heat stress near the end of this event, suggesting the mortality was not heat stress-driven. As of September 2016, scientists continued exploring a broad spectrum of possible causes, including poor water quality, disease pathogens and chemical spills that may have worked in concert to cause mortality event. In September and October 2016, a mass bleaching event – the worst on record for the FGBNMS – was reported by local research and management partners. Field observations indicated that by mid-October, SSTs greater than 30°C had persisted in the region for 85 days, and at the East Flower Garden Banks site, almost 50% of the coral colonies were bleached or paling. Bleaching also was reported in other areas of the Sanctuary. Data received from partners in 2016 aligned well with CRW's 5km satellite monitoring for the FGBNMS.

#### Puerto Rico:

In 2016, based on its 5km satellite monitoring and its Four-Month Outlook, CRW issued a Bleaching Warning for Puerto Rico on September 16, which lasted until October 4 (Figure 8). A brief Bleaching Warning was issued again from October 16-22 and November 12-18, but the heat stress did not elevate to Alert Level 1 (Figures 8, 9). This was confirmed by CRW's 50km satellite monitoring from September through November 2016 (Figure 10).



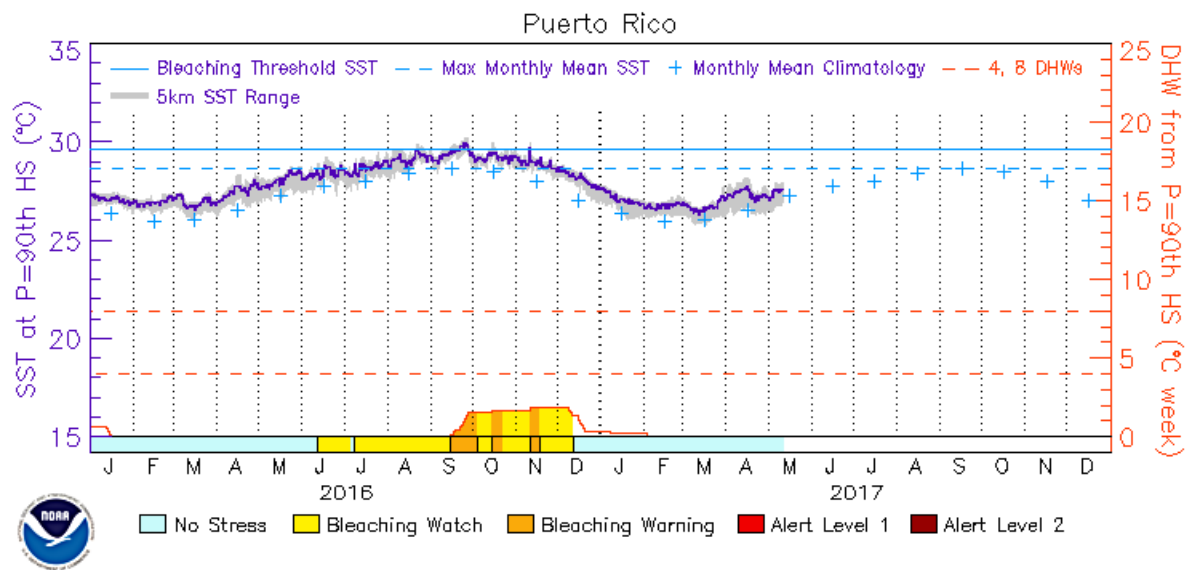


Figure 8. Two-year (January 1, 2016-present) time-series graph for CRW’s 5km Regional Virtual Station for Puerto Rico. See the Figure 3 caption for how to read the graph.

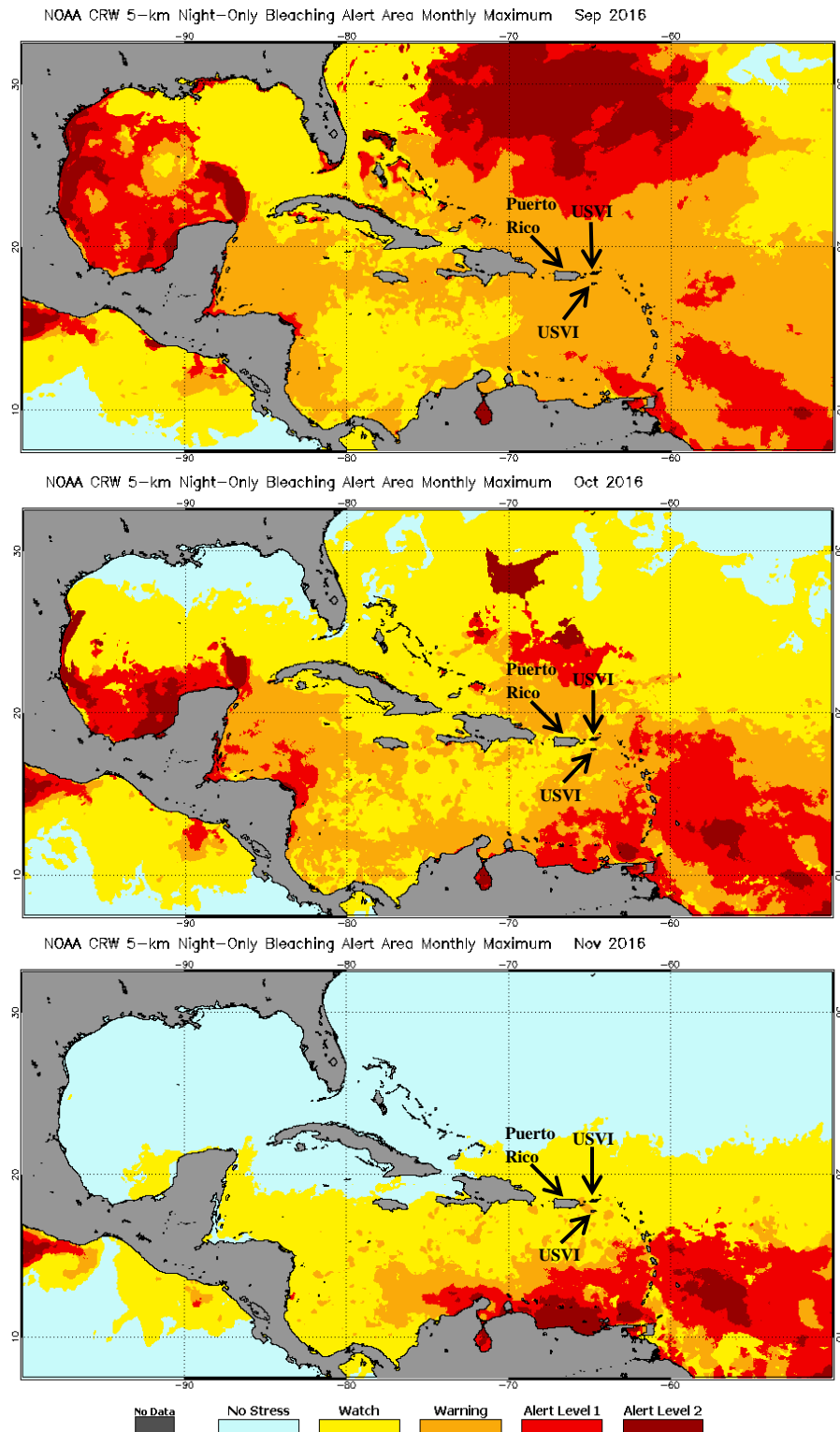


Figure 9. CRW's 2016 monthly maximum composite of the daily 5km Bleaching Alert Area for the Greater Caribbean region for September (top panel), October (middle panel), and November 2016 (bottom panel).

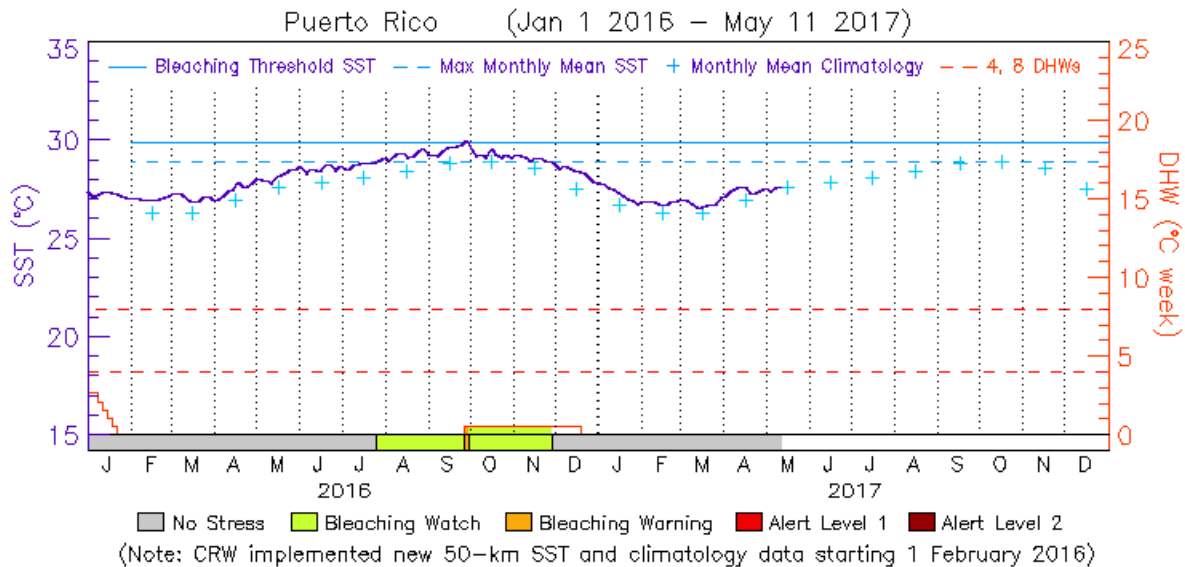


Figure 10. Two-year (January 1, 2016-present) time-series graph for CRW's 50km Virtual Station for Puerto Rico. See the Figure 3 caption for how to read the graph.

Mild bleaching (mostly paling of coral colonies) was reported in Puerto Rico as of mid-November 2016. However, local partners suggested that the mild bleaching could be attributed to the unusually high amount of precipitation, high primary productivity, and high organic particles in suspension in the region. Hence, it most likely was not attributed to the mild heat stress identified by CRW's satellite monitoring intermittently between September and November 2016. However, CRW's satellite monitoring suggests that the heat stress in Puerto Rico has reached the upper limit of most corals' tolerance level two years in a row as part of large scale moderately-warm SST anomalies in the Atlantic Ocean to the north and southwest of the island (Figure 9).

#### U.S. Virgin Islands:

The U.S. Virgin Islands (USVI) is located to the east and southeast of Puerto Rico (Figure 9). Based on its 5km satellite monitoring in 2016, CRW's first issuance of a Bleaching Warning in the Virgin Islands region (which includes the USVI and the British Virgin Islands) was August 23-September 3 (Figure 11). A short-lived Bleaching Warning was issued again from September 17-October 4, October 14-22, October 31-November 6, and, November 12-18, 2016. Lower than the levels experienced in 2015, the heat stress did not escalate beyond Bleaching Warning conditions in 2016, and a level of No Stress was finally reached as of December 13. As with Puerto Rico, the USVI (located even closer to the warmer waters) was influenced by larger scale warm SST anomalies to the north and southwest in the Atlantic Ocean (Figure 9).

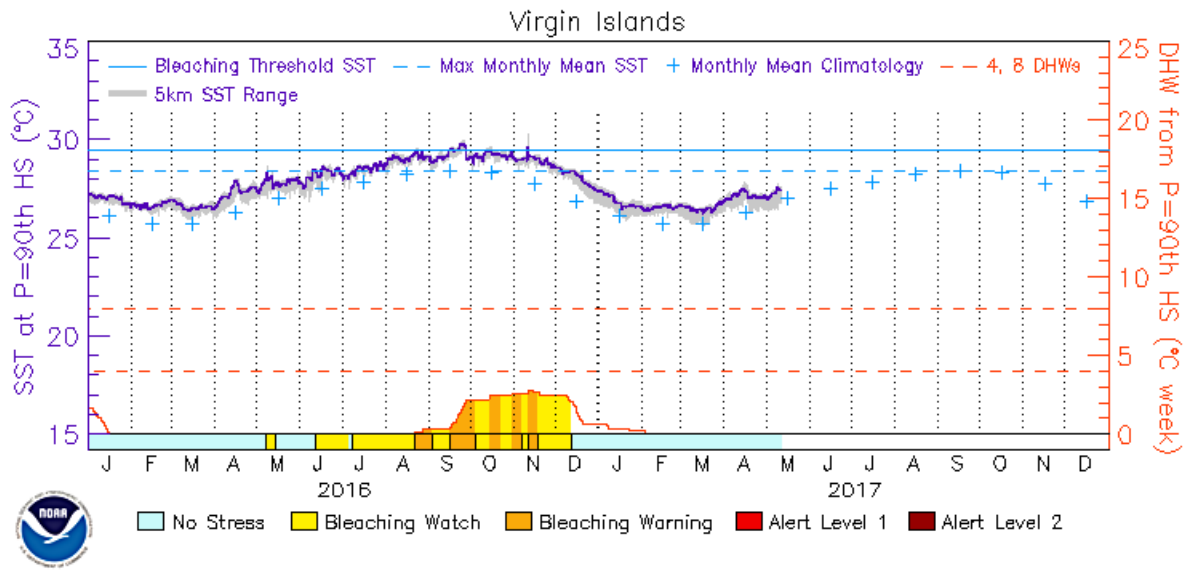


Figure 11. Two-year (January 1, 2016-present) time-series graph for CRW's 5km Regional Virtual Station for the Virgin Islands (which includes the U.S. Virgin Islands and the British Virgin Islands). See the Figure 3 caption for how to read the graph.

CRW's 50km satellite monitoring for the USVI Virtual Station agreed well with the 5km satellite monitoring for the Virgin Islands region throughout summer 2016 but was slightly more conservative in its estimates of heat stress. Per the 50km satellite monitoring, a Bleaching Watch was in effect from July 18-December 5 but only elevated to a Bleaching Warning once within that period, from September 22-29, 2016 (Figure 12).

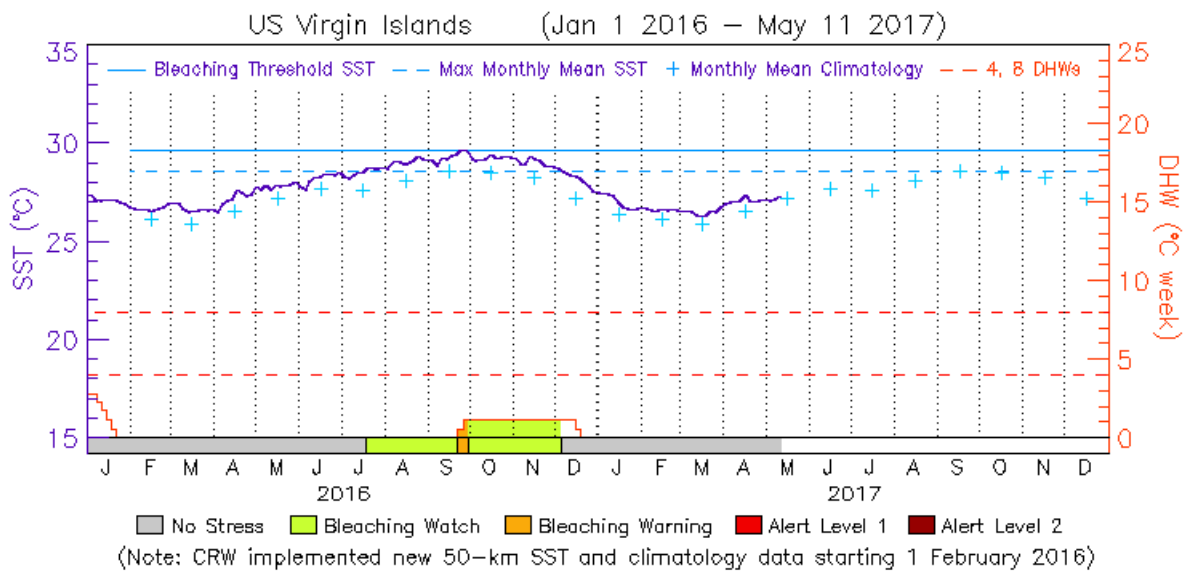


Figure 12. Two-year (January 1, 2016-present) time-series graph for CRW's 50km Virtual Station for the U.S. Virgin Islands. See the Figure 3 caption for how to read the graph.

As of this writing, CRW has yet to receive reports of bleaching on coral reefs of the USVI in 2016 from local resource management and research partners. This aligns well with CRW's satellite

monitoring (at both 5km and 50km spatial resolutions), which indicated the presence of only mild heat stress in the USVI during summer and autumn 2016.

## PACIFIC OCEAN

### Hawaii:

From the end of 2015 through December 2016, CRW's 5km (Figures 13, 14) and 50km (Figures 15, 16) satellite products detected little heat stress capable of causing mass coral bleaching throughout the Hawaiian archipelago, although the temperatures there were again above the long-term average – giving corals and other organisms a much-needed reprieve from climate-driven heat stress to recover and repopulate reef ecosystems in the region.

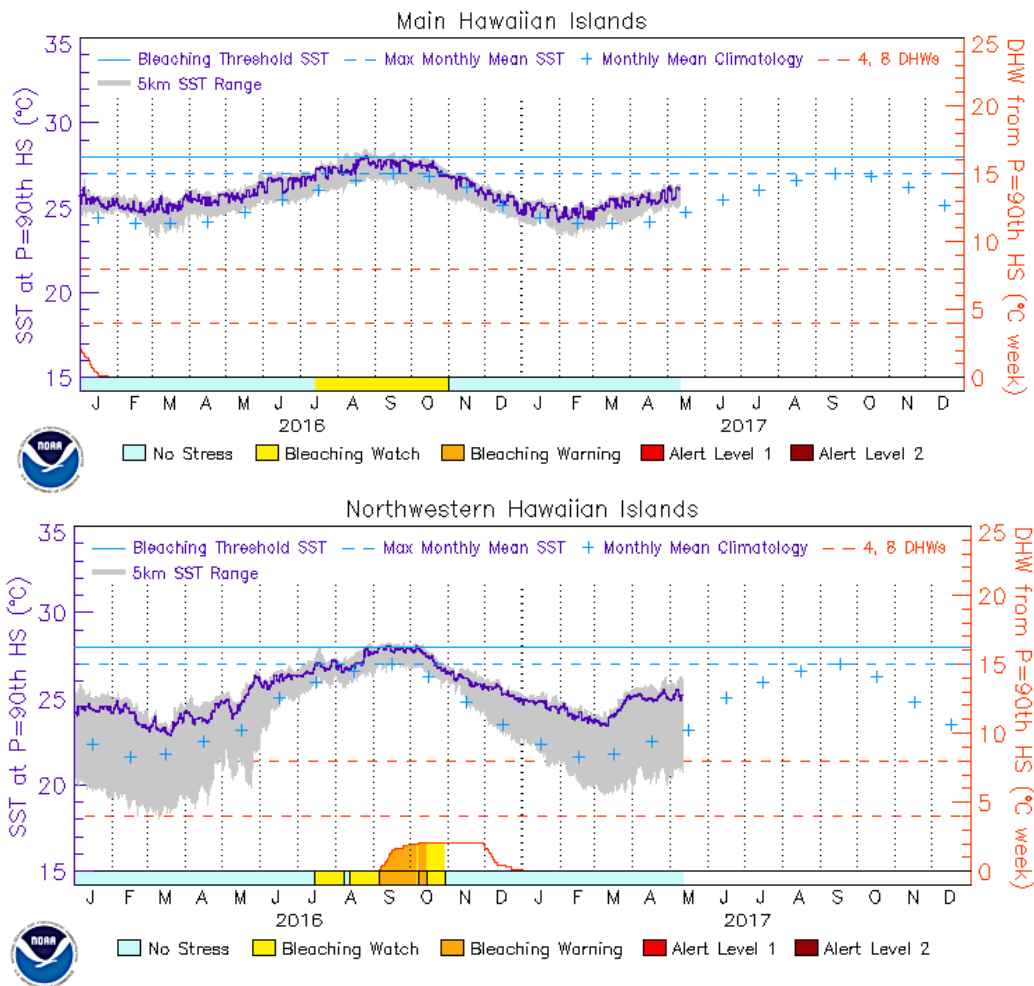


Figure 13. Two-year (January 1, 2016-present) time-series graph for CRW's 5km Regional Virtual Stations for the Main Hawaiian Islands (top panel) and the Northwestern Hawaiian Islands (NWHI, bottom panel). Note that the large SST range (grey shading) within the NWHI Station is the result of its wide geographic extent. See the Figure 3 caption for how to read the graph.

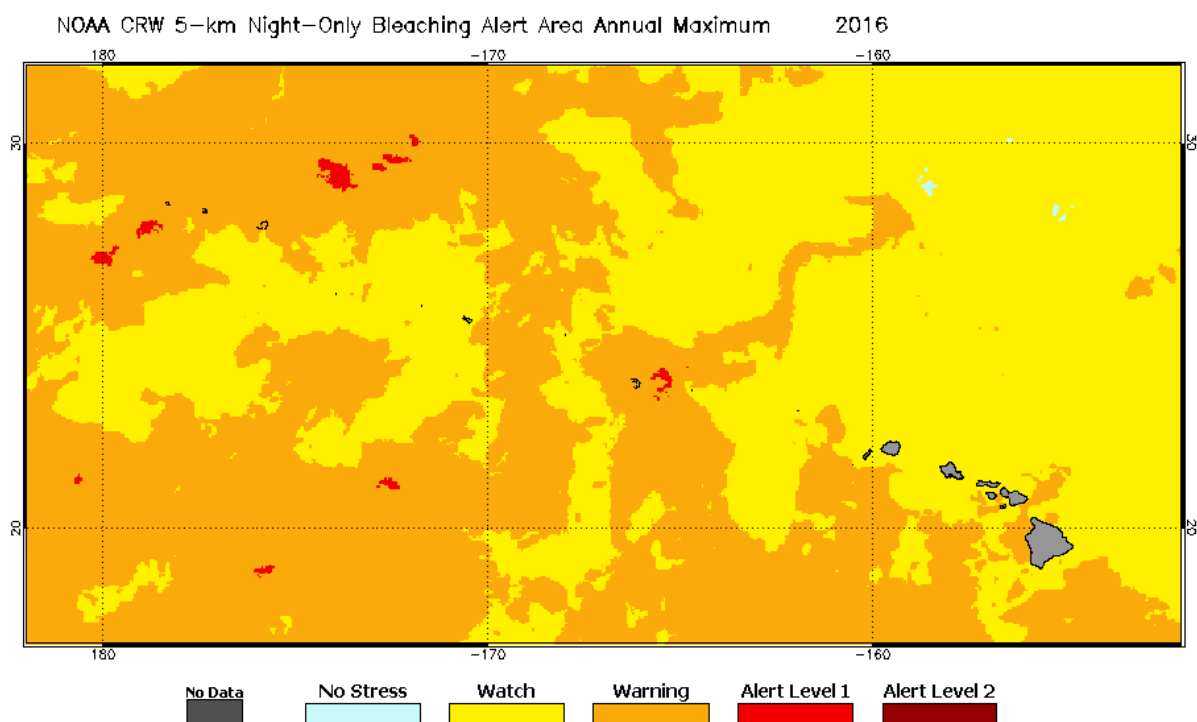


Figure 14. CRW's 2016 annual maximum composite of its daily 5km Bleaching Alert Area for the Hawaiian Islands.



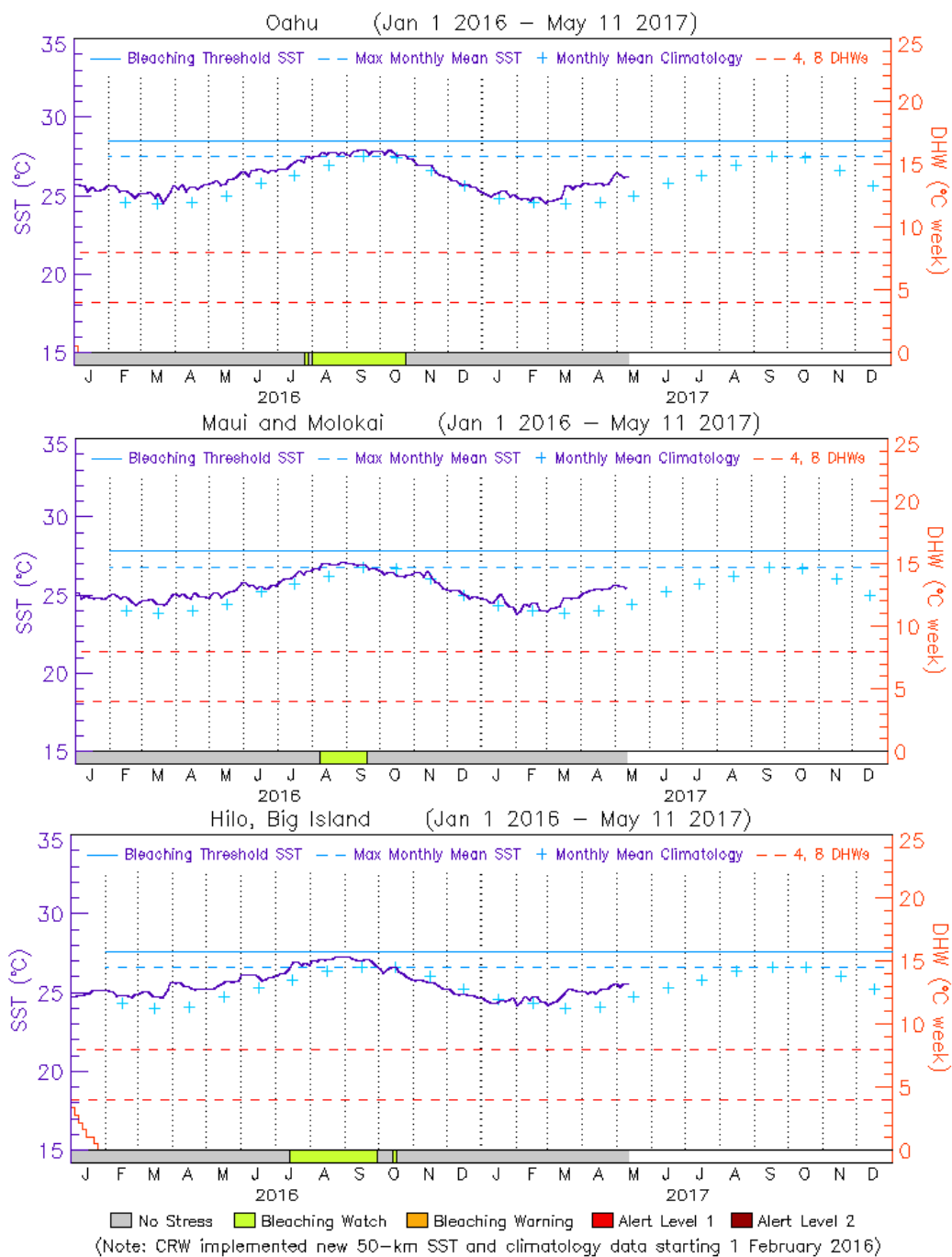


Figure 15. Two-year (January 1, 2016-present) time-series graphs for CRW’s 50km Virtual Stations at Oahu (top panel), Maui and Molokai (middle panel), and Hilo, Big Island, Hawaii (bottom panel). See the Figure 3 caption for how to read the graph.

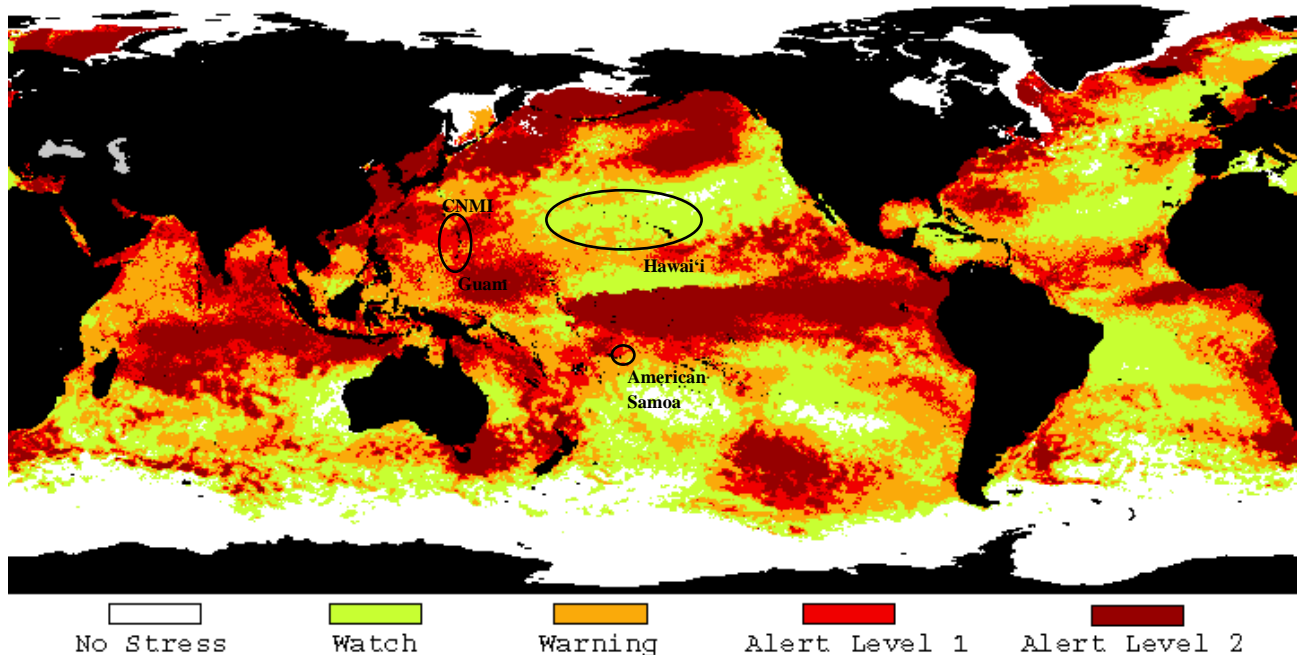


Figure 16. CRW's 2016 annual maximum composite of its twice-weekly global 50km Bleaching Alert Area. The U.S. coral reef jurisdictions in the Pacific (Guam and the Commonwealth of the Northern Mariana Islands [CNMI], Hawai'i, and American Samoa) are circled in black.

As of this writing, no major bleaching was reported by local resource management and research partners in the Hawaiian archipelago in 2016.

#### American Samoa:

American Samoa is located in the Southern Hemisphere and has a bleaching season that straddles two calendar years. In November/December 2015, the record-strength El Niño event peaked. This brought another round of heat stress to coral reefs in the Southern Hemisphere. Extremely high temperatures along the central and eastern equatorial Pacific fueled the development of heat stress in the central-to-western South Pacific Ocean. On November 12, 2015, CRW's 5km Samoas Regional Virtual Station, covering both American Samoa and the Independent State of Samoa (Figure 17), registered a Bleaching Watch. That stress elevated to a Bleaching Warning as of February 2-23 and again from March 22-31, 2016 (Figure 18). It then escalated further to Alert Level 1 heat stress from April 1-27. Although the heat stress level downgraded to a Bleaching Watch on April 28, DHWs  $\geq 4$  persisted at the 5km Samoas Regional Virtual Station until June 21. The development of significant bleaching heat stress in the Samoas, from February through June 2016, was confirmed by CRW's 50km satellite monitoring at Tutuila, Ofu, and Swains Island, American Samoa (Figure 19). The highest level of heat stress detected by CRW's 50km Virtual Station at Rose Atoll, American Samoa during this same period was a Bleaching Warning, issued in early April 2016 (Figure 20).

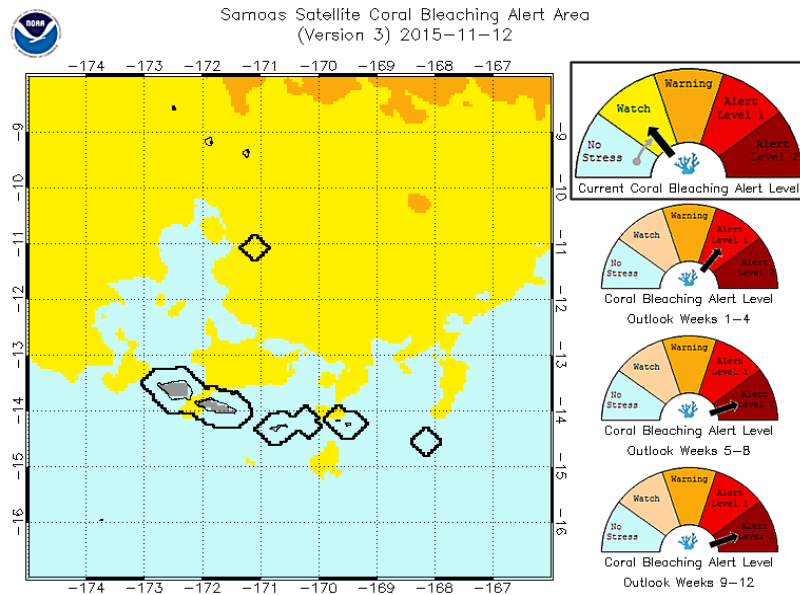


Figure17. Spatial coverage (black polygons) of CRW's 5km Samoa Regional Virtual Station on a map of CRW's 5km 7-day maximum Bleaching Alert Area for November 12, 2015, when the Station registered a Bleaching Watch. Bleaching Heat Stress Gauges (right of map) indicate the Station's heat stress level that day (black box) and predicted levels for the following 1-4, 5-8, and 9-12 weeks.

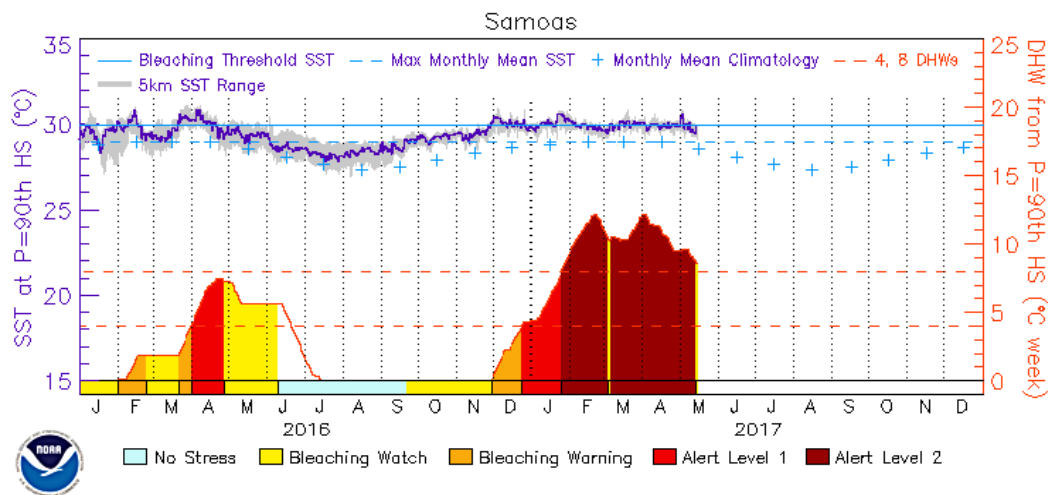


Figure18. Two-year (2016-present) time-series graph for CRW's 5km Samoa Regional Virtual Station. See the Figure 3 caption for how to read the graph.

During the second half of 2016, the 5km Samoa Regional Virtual Station first monitored heat stress corresponding to a Bleaching Watch on September 22. That stress elevated to a Bleaching Warning on November 30 and further to Alert Level 1 as of December 25, 2016 (Figure 18). As of December 27, 2016, CRW's Four-Month Coral Bleaching Heat Stress Outlook issued on December 27, 2016 predicted that Alert Level 2 heat stress would arrive in the Samos region in January 2017 and last through at least the end of April 2017 (Figure 21). CRW's 5km satellite monitoring would later indicate Alert Level 1 heat stress lasted in the Samoa until late January 2017, before escalating further to Alert Level 2 conditions, which persisted into early May 2017.

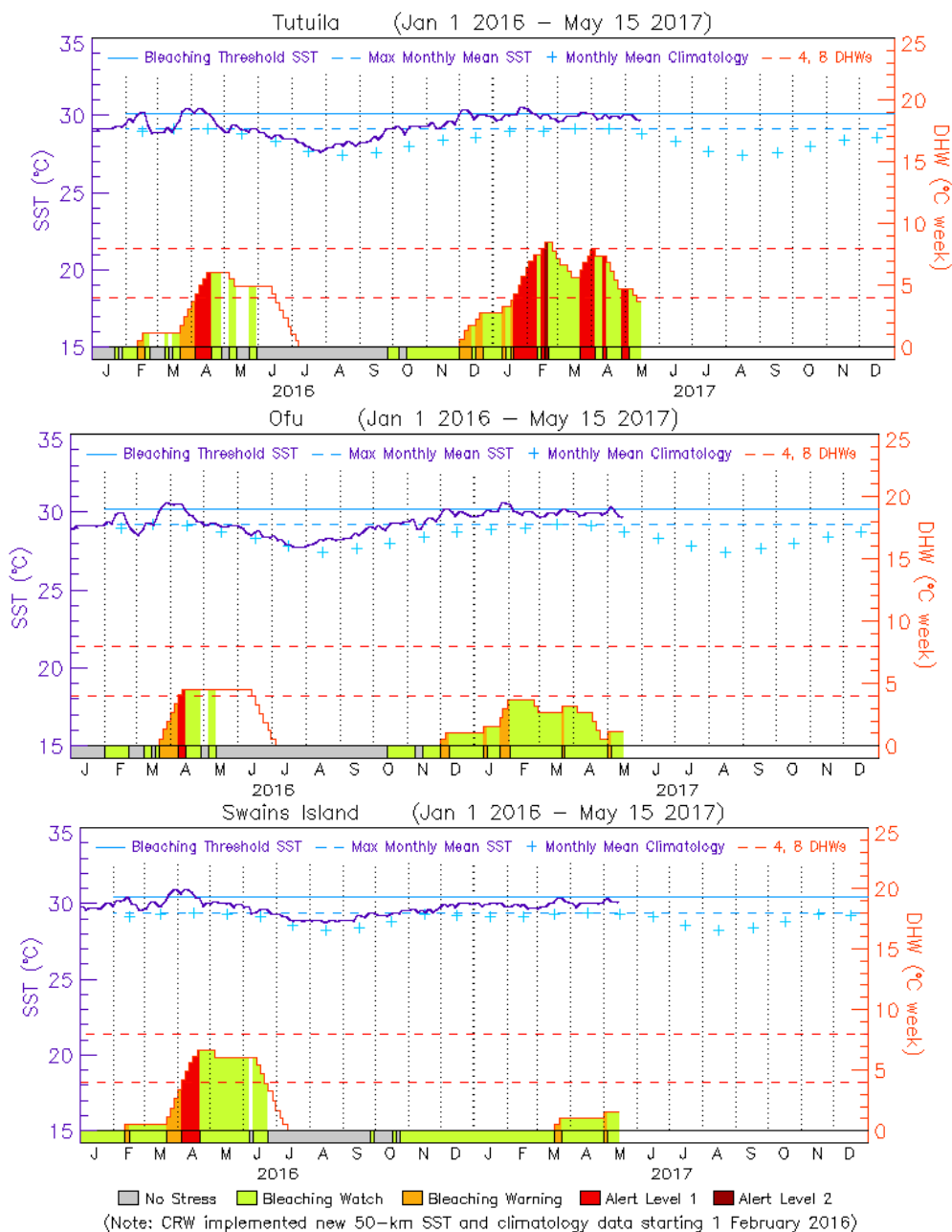


Figure 19. Two-year (2016-present) time-series graph for CRW's 50km Virtual Station at (a) Tutuila, (b) Ofu, and (c) Swains Island, American Samoa. See the Figure 3 caption for how to read the graph.

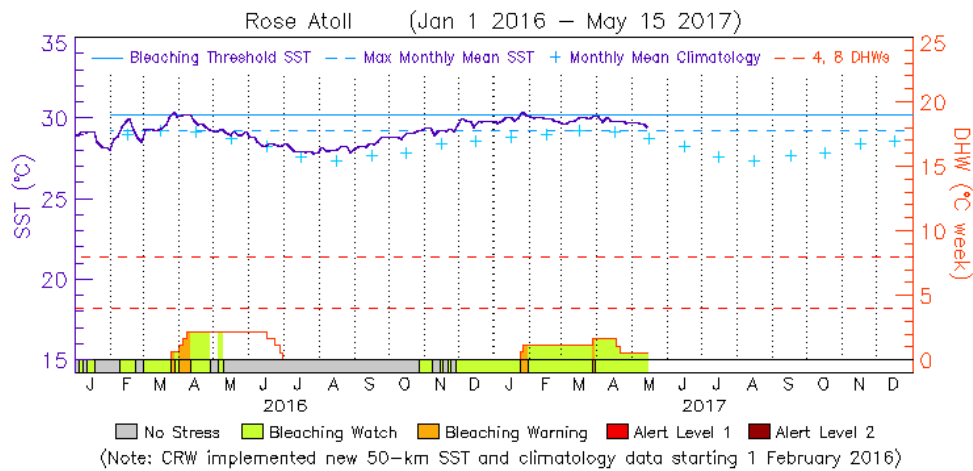


Figure 20. Two-year (2016-present) time-series graph for CRW's 50km Virtual Station at Rose Atoll, American Samoa. See the Figure 3 caption for how to read the graph.

Although CRW's 5km and 50km satellite coral bleaching products both monitored the presence of high heat stress (Alert Level 1) in the Samoas in April 2016 and the persistence of  $DHW \geq 4$  through June 2016, between November 2015 and June 2016, CRW did not receive any reports of coral bleaching from local management and research partners in American Samoa and Independent Samoa. This does not necessarily mean coral bleaching did not occur on local reefs; reports, if any, may have not been sent to CRW. To better understand the performance of its 5km and 50km satellite monitoring for the Samoas during that time, CRW continues to reach out to field partners to obtain observations of bleaching/no bleaching from the first half of 2016.

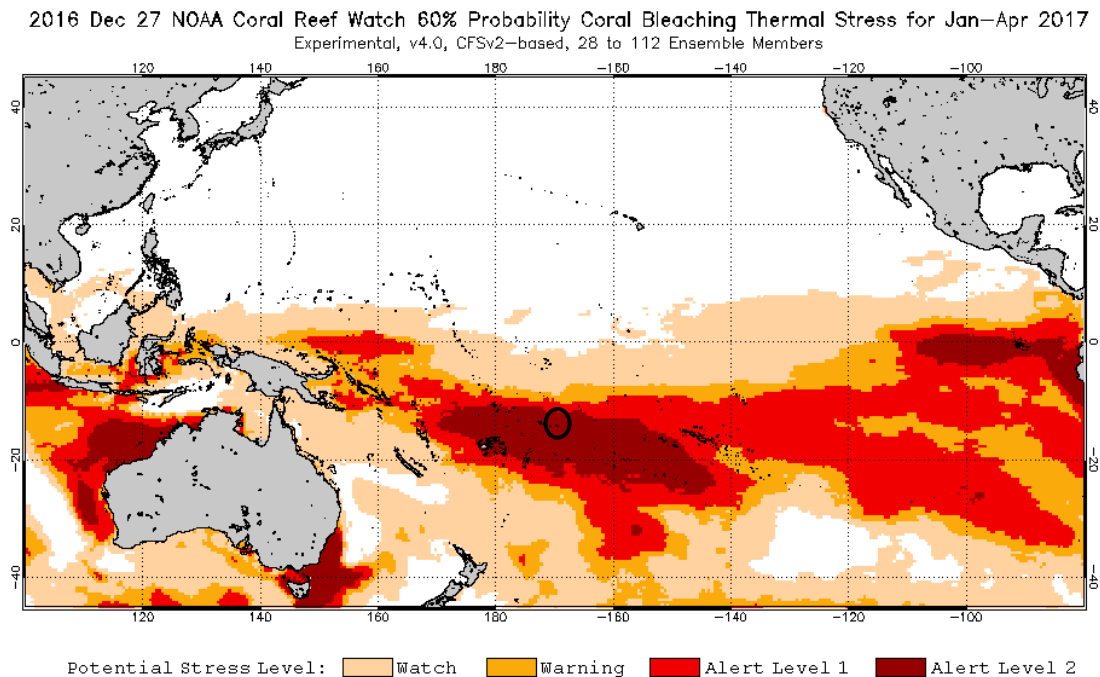


Figure 21. Map of potential coral bleaching heat stress (60% probability) in the Pacific for January-April 2017 from NOAA CRW's Four-Month Coral Bleaching Heat Stress Outlook (version 4) of December 27, 2016, based on NOAA's Climate Forecast System v2 SST predictions. American Samoa is circled in black.

CRW's 50km satellite monitoring was slightly more conservative in its identification of the onset of mass bleaching heat stress, and the level of severity, in American Samoa in the second half of 2016. Similar to the 5km Samoas Regional Virtual Station, the 50km Virtual Station at Tutuila first detected the onset of a Bleaching Watch on September 26, 2016. However, Ofu, Swains Island, and Rose Atoll did not register a Bleaching Watch until October 13, October 17, and October 27, 2016, respectively (Figures 19 and 20). The 50km satellite monitoring at the Ofu, Swains Island, and Rose Atoll Virtual Stations also did not detect significant coral bleaching heat stress (Alert Levels 1 and 2) through the end of 2016 and into 2017. Alert Level 1 bleaching stress was monitored at the 50km Virtual Station for Tutuila, but not until mid-January 2017; it also only elevated to Alert Level 2 for one week in mid-February 2017 (Figure 19).

Since only low levels of bleaching heat stress were detected by CRW's 5km and 50km satellite monitoring throughout the second half of 2016 – until December 25, 2016, it is not surprising that CRW only received one report of minor bleaching of staghorn corals around Tutuila, American Samoa on October 25, 2016 (when the area was under a Bleaching Watch). However, CRW continues to reach out to field partners to obtain observations of bleaching/no bleaching from the second half of 2016, to validate the performance of its high-resolution and heritage satellite monitoring in this region. Note that as of this writing, CRW has received multiple reports that coral bleaching and mortality escalated throughout American Samoa from mid- to late-March 2017, at a time when the 5km Samoas Regional Virtual Station was registering Alert Level 2 heat stress (Figure 18) and the 50km Virtual Station at Tutuila was registering Alert Level 1 conditions (Figure 19).

Consistent with CRW's 5km satellite coral bleaching products, widespread bleaching was reported around the island of Tutuila by Territorial and Park Service researchers. Unlike the 2015 bleaching, 2017 bleaching extended well out onto the reef slope, affected corals deeper than the prior event. Less reports were received from Independent Samoa, where bleaching also was reported to last into May 2017. CRW continues collating bleaching reports from the field from the first half of 2017 (which will be reported in the 2017 annual summary of bleaching heat stress conditions in the U.S. jurisdictions); however initial reports, especially around the island of Tutuila, align more closely with CRW's 5km satellite coral bleaching monitoring than its heritage 50km satellite monitoring.

#### *Guam and the Commonwealth of the Northern Mariana Islands (CNMI):*

Back-to-back record heat stress and coral bleaching events occurred in the Commonwealth of the Northern Mariana Islands (CNMI) and Guam in 2013 and 2014. Again in 2015, CRW's satellite monitoring detected heat stress in both Guam and the CNMI, but it was not at a level high enough to cause significant bleaching. This was expected to have given both regions a much needed reprieve from climate-related heat stress and providing an opportunity for potential recovery and growth of corals and other reef organisms damaged during the previous two years' major bleaching. However, extreme low tides due to the 2015-16 El Niño coupled with calm winds and sun caused significant bleaching and mortality in some restricted bodies of water, especially in Tumon Bay, Guam.

Two 5km Regional Virtual Stations exist for Guam and the CNMI (or Northern Mariana Islands). In 2016, a Bleaching Watch was first detected in Guam on May 18 and in the Northern Mariana Islands on May 26 (Figures 22 and 23). After both regions fluctuated between Bleaching Watch and



Bleaching Warning status throughout June and July, Alert Level 1 bleaching heat stress first appeared at the 5km Regional Virtual Station for the Northern Mariana Islands on July 30, lasting until August 18, 2016 (Figure 24). Alert Level 1 stress was monitored then in Guam on August 26 and again in the Northern Mariana Islands on August 28, lasting in both regions through early September (Figure 24). Cooler waters arrived at that time, returning the stress level to a Bleaching Watch in both Guam and the CNMI. A short-lived burst of Alert Level 1 heat stress was monitored by the 5km Regional Virtual Station for the Northern Mariana Islands from October 9-15, but otherwise, from September through the end of December 2016, only low levels of heat stress (Bleaching Watch and Bleaching Warning) were detected by CRW's 5km satellite monitoring in Guam and the CNMI.

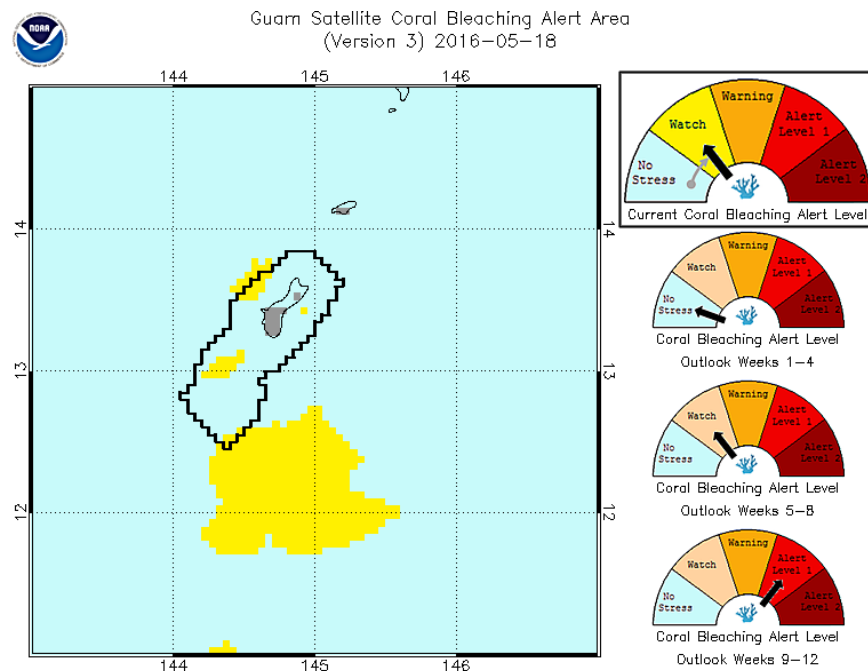


Figure 1. Spatial coverage (black polygons) of CRW's 5km Guam Regional Virtual Station on a map of CRW's 5km 7-day maximum Bleaching Alert Area for May 18, 2016, when the Station first reached Bleaching Watch status in 2016. Bleaching Heat Stress Gauges (right of map) indicate the Station's heat stress level that day (black box) and predicted levels for the following 1-4, 5-8, and 9-12 weeks.

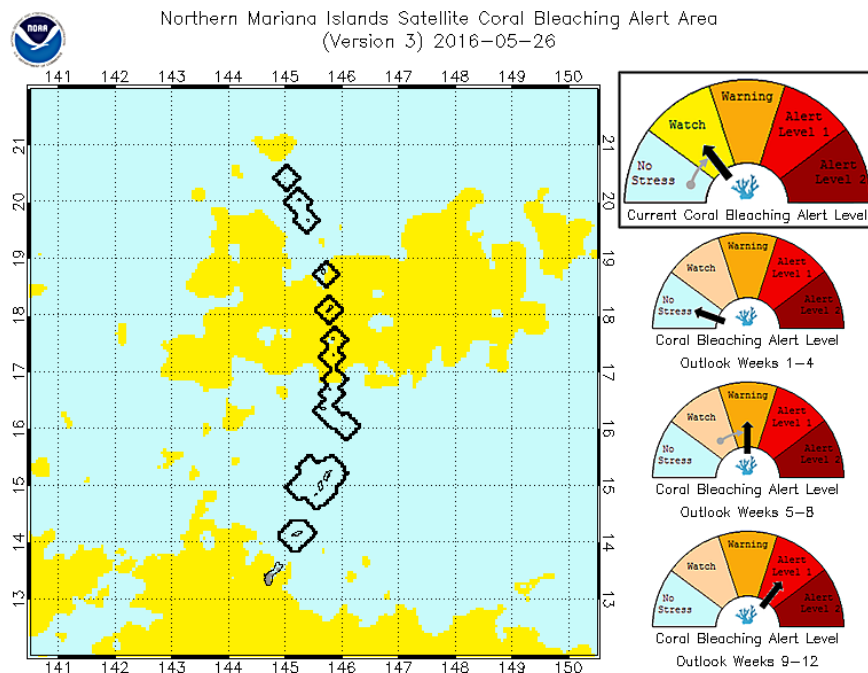
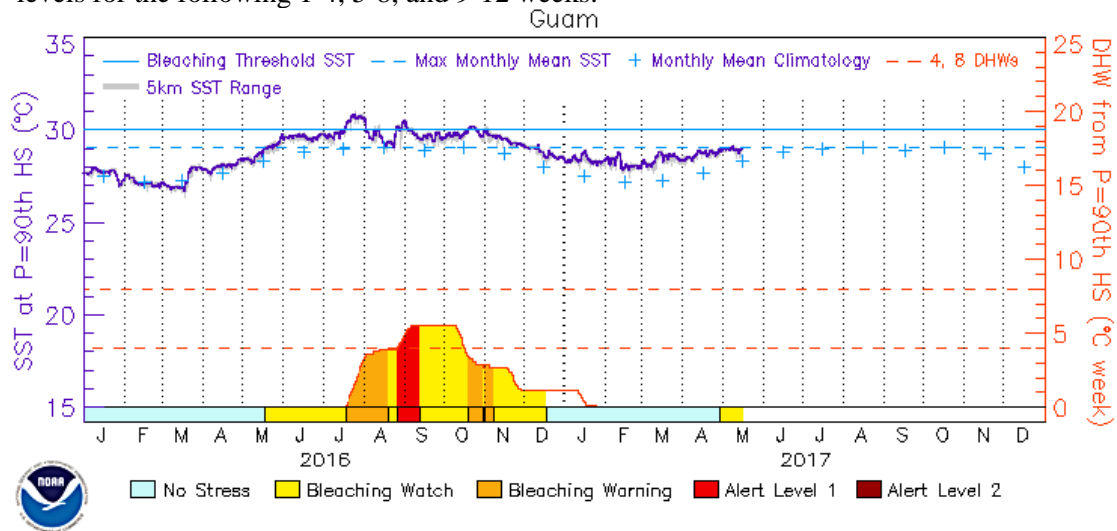


Figure 23. Spatial coverage (black polygons) of CRW's 5km Northern Mariana Islands Regional Virtual Station on a map of CRW's 5km 7-day maximum Bleaching Alert Area for May 26, 2016, when the Station first reached Bleaching Watch status in 2016. Bleaching Heat Stress Gauges (right of map) indicate the Station's heat stress level that day (black box) and predicted levels for the following 1-4, 5-8, and 9-12 weeks.



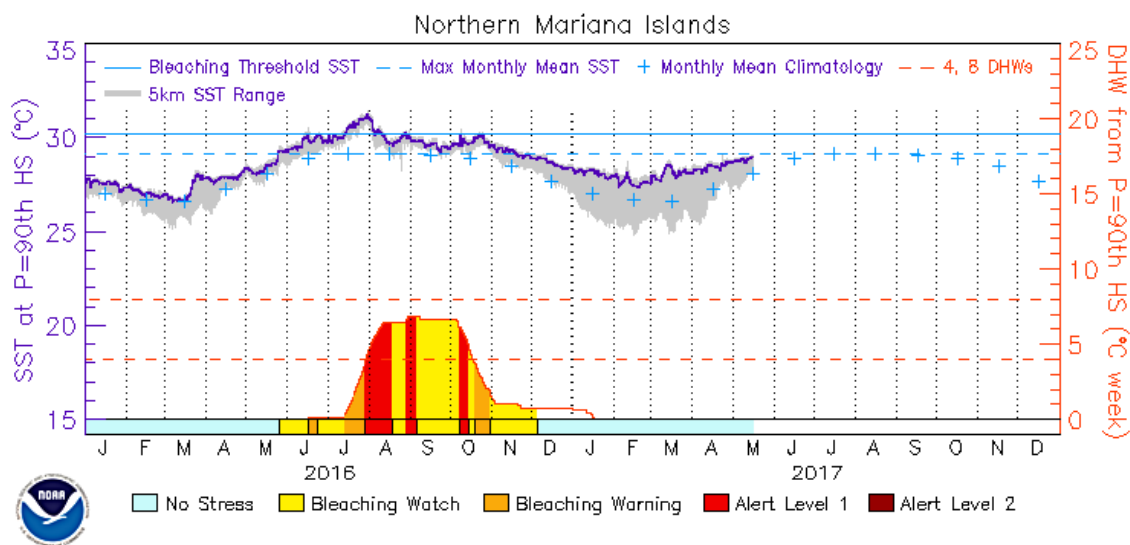


Figure 24. Two-year (2016-present) time-series graphs for CRW's 5km Guam (top panel) and Northern Mariana Islands (bottom panel) Regional Virtual Stations. See the Figure 3 caption for how to read the graph.

Guam and the CNMI are served by ten CRW 50km Virtual Stations. From south to north, these are Santa Rosa Reef, Guam, Guam East (for Guam), Rota Island, Saipan and Tinian, Sarigan and Anatahan, Guguan and Alamagan, Pagan Island, Agrihan and Asuncion, Maug Island, and Urracas (for the CNMI) (Figure 25). Time-series graphs for the Agrihan and Asuncion, Maug Island, and Urracas Stations, at the northern end of the CNMI, are provided in Figure 26 as example 50km CNMI Virtual Stations; time-series graphs for the 50km Guam East and Santa Rosa Reef, Guam Virtual Stations are provided in Figure 27.

CRW's 50km satellite monitoring was slightly more conservative in its identification of the onset of bleaching heat stress in Guam (May 26) and throughout the CNMI (June 6) in 2016, first detecting the heat stress development eight days and 11 days, respectively, after the 5km satellite products for each region. In the northernmost portion of the CNMI, however, CRW's 50 Virtual Stations at Maug Island and Urracas then detected the development of Alert Level 1 bleaching heat stress slightly earlier than the 5km Northern Mariana Islands Regional Virtual Station; i.e., on July 18 (Maug Island) and July 25 (Urracas). Both 50km Virtual Stations also monitored short bursts of Alert Level 2 bleaching heat stress from August 1-11 and August 11-15, respectively, that the 5km Northern Mariana Islands Station did not detect (although the 5km satellite products were registering Alert Level 1 bleaching heat stress at the time). This may have to do with the location and extent of the 50km satellite pixels for the Maug Island and Urracas Virtual Stations, which extend outside of the range of the 5km Northern Mariana Islands Regional Virtual Station and were thus able to capture heat stress to the north and northeast of the CNMI at that time that the 5km satellite pixels nearer to and encompassing the islands did not. Thereafter, however, CRW's 50km satellite monitoring at all of the CNMI Virtual Stations did not detect the short burst of Alert Level 1 heat stress from October 9-15 that the 5km Northern Mariana Islands Regional Virtual Station monitored. This suggests that the location and extent of the bleaching heat stress, if actually present, was closer to or along the coast of the CNMI islands and was therefore detectable by the 5km satellite products but was masked by the land-mask in the 50km satellite products. Where it concerns the retreat of bleaching heat stress from the CNMI in 2016, most of the CNMI 50km Virtual Stations showed the heat stress dissipated by early-November (Figure 26) – one month

before CRW's 5km satellite products showed the decrease, whereas the 50km Virtual Stations at Sarigan and Anatahan and Rota Island compared more closely with the 5km Northern Mariana Islands Regional Virtual Station, indicating the heat stress finally dissipated in late November.

Note that while CRW's 50km satellite monitoring identified the onset of bleaching heat stress in Guam slightly after the 5km satellite products, the two 50km Guam Virtual Stations monitored the subsequent development and retreat of bleaching heat stress in the region throughout summer and autumn 2016, including the presence of the short-lived Alert Level 1 heat stress from late August until early September 2016, comparably with the 5km satellite products.

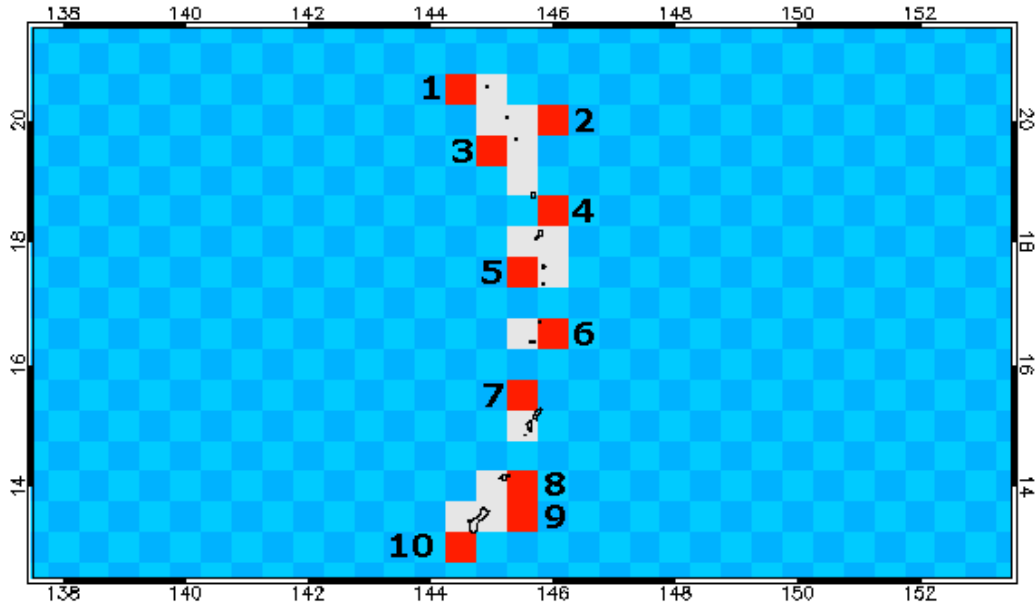


Figure 25. CRW's single satellite pixel-based 50km Virtual Stations (red squares) for the Commonwealth of the Northern Mariana Islands (CNMI) and Guam: (1) Urracas, (2) Maug Island, (3) Agrihan and Asuncion, (4) Pagan Island, (5) Guguan and Alamagan, (6) Sarigan and Anatahan, (7) Saipan and Tinian, (8) Rota Island, (9) Guam East, and (10) Santa Rosa Reef, Guam. Pixels in white are land-mask pixels.

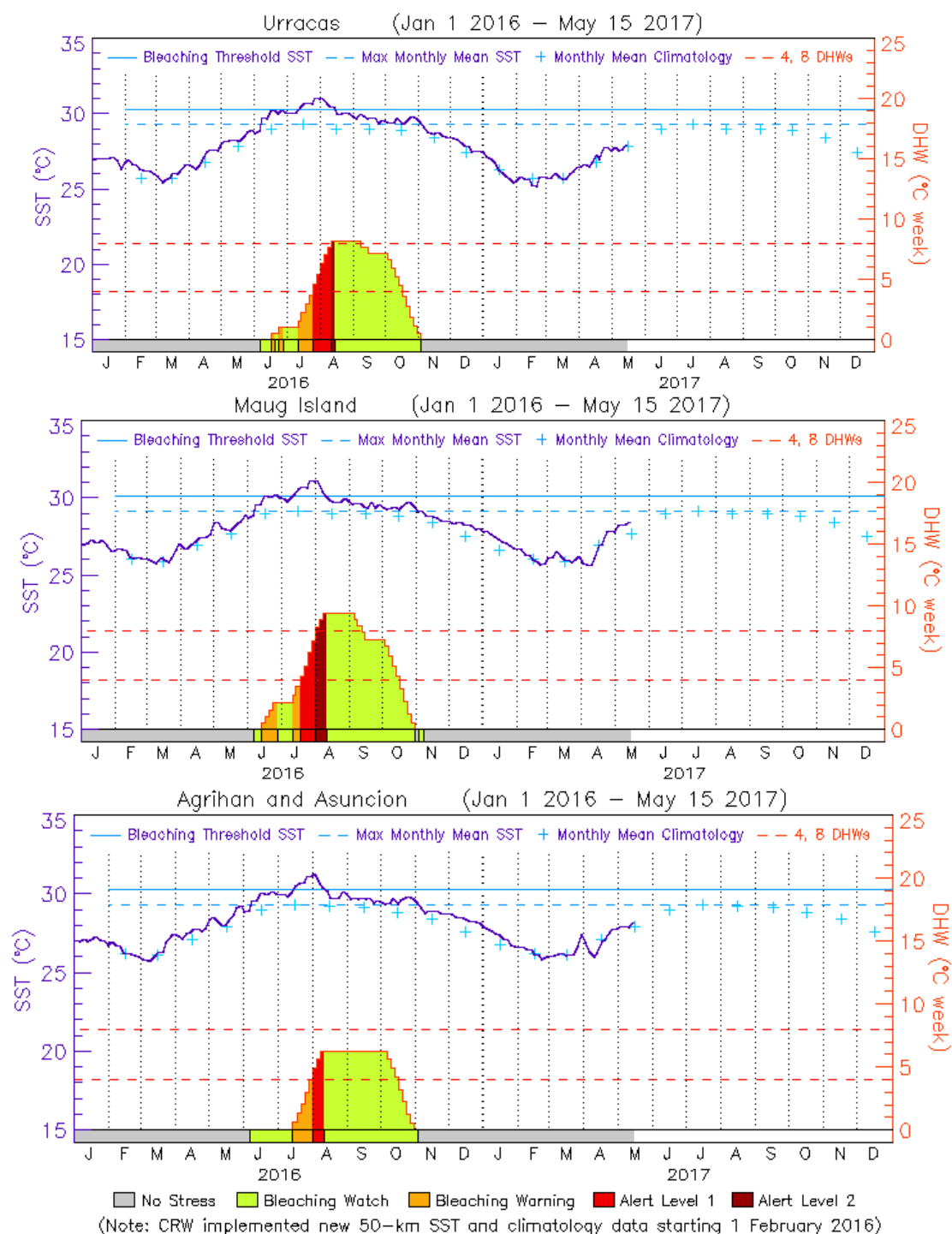


Figure 26. Two-year (2016-present) time-series graphs for CRW's 50km Urracas (top panel), Maug Island (middle panel), and Agrihan and Asuncion (bottom panel) Virtual Stations. See the Figure 3 caption for how to read the graph.

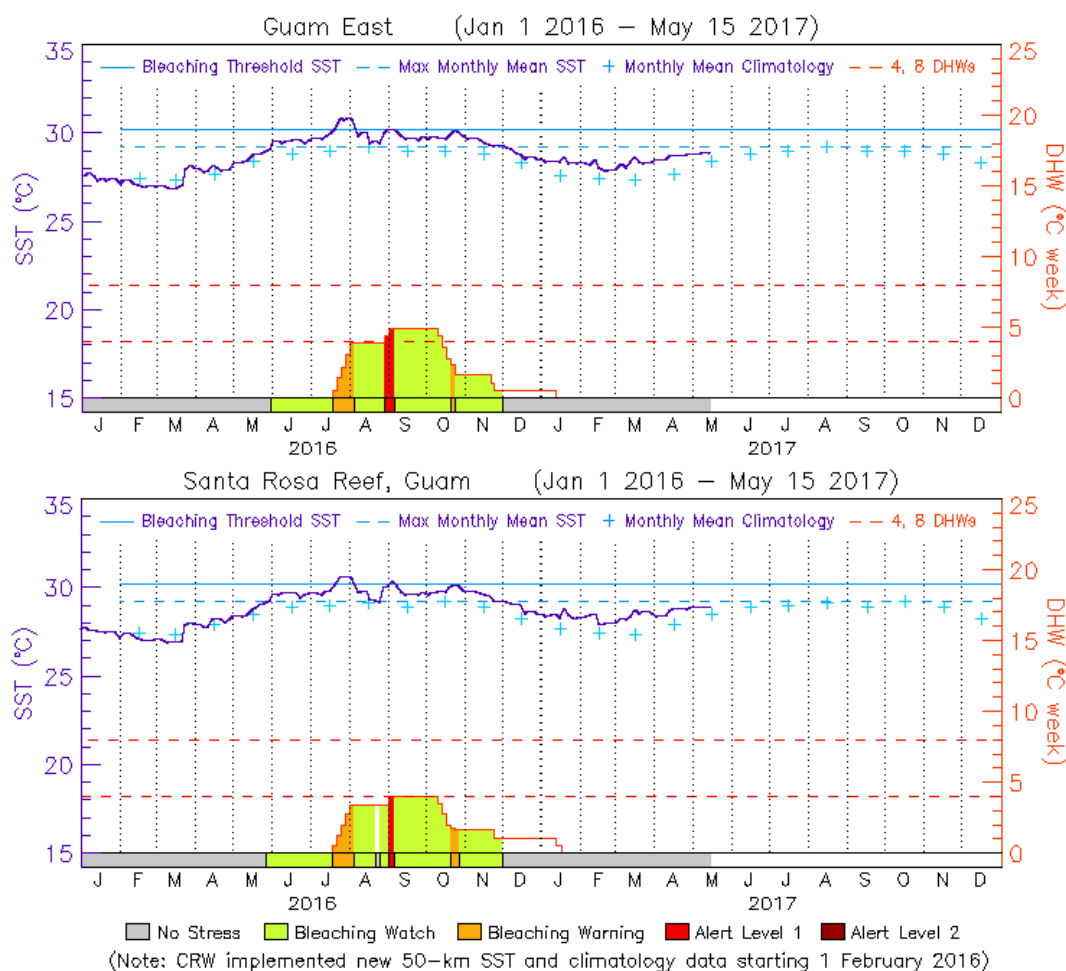


Figure 27. Two-year (2016-present) time-series graphs for CRW's 50km Guam East (top panel) and Santa Rosa Reef, Guam (bottom panel) Virtual Stations. See the Figure 3 caption for how to read the graph.

CRW first received reports of bleaching from local management and research partners in the CNMI and Guam at the end of July 2016, when severe bleaching of *Acropora* corals was observed in Saipan (especially in the reef slope area of Saipan lagoon) and severe bleaching of multiple coral species was documented in Tumon Bay, Guam. Initial bleaching observations in the CNMI at the end of July align more closely with CRW's 5km monitoring at the Northern Mariana Islands Regional Virtual Station (which registered Alert Level 1 heat stress as of July 30) than CRW's 50km monitoring, which showed all of the CNMI Virtual Stations (excluding Maug Island and Urracas) were under a Bleaching Warning until the beginning of August, when conditions then elevated to Alert Level 1 (Figures 24, 26, and 27). The initial bleaching observations in Guam at the end of July 2016 aligned with the onset of warming in CRW's 5km and 50km satellite monitoring. The low-level heat stress in July was below that which normally causes this level of bleaching and Alert Level 1 heat stress did not appear in the region until late August 2016. Bleaching continued after August, resulting in some mortality – especially in soft corals. CRW is seeking additional reports from August through December 2016, as it received few reports of coral bleaching or mortality during this time, even though CRW's 5km and 50km satellite products monitored significant bleaching heat stress (Alert Levels 1 and 2) on multiple occasions in specific areas of the CNMI and Guam in August, September, and October 2016 (Figures 24, 26, and 27).



## References:

Eakin, CM, Liu G, Gomez AM, De La Cour JL, Heron SF, Skirving WJ, Geiger EF, Tirak KV, Strong AE (2016) Global Coral Bleaching 2014-2017: Status and an Appeal for Observations. **Reef Encounter** 43 31(1): 20-26.

Heron, S.F.; Johnston, L.; Liu, G.; Geiger, E.F.; Maynard, J.A.; De La Cour, J.L.; Johnson, S.; Okano, R.; Benavente, D.; Burgess, T.F.R.; Iguel, J.; Perez, D.; Skirving, W.J.; Strong, A.E.; Tirak, K.; Eakin, C.M. Validation of Reef-scale Thermal Stress Satellite Products for Coral Bleaching Monitoring. **Remote Sensing** 2016, 8(1), 59, doi: 10.3390/rs8010059.

Liu, G, Heron SF, Eakin CM, Muller-Karger FE, Vega-Rodriguez M, Guild LS, De La Cour JL, Geiger EF, Skirving WJ, Burgess TFR, Strong AE, Harris A, Maturi E, Ignatov A, Sapper J, Li J, Lynds S (2014). Reef-scale Thermal Stress Monitoring of Coral Ecosystems: New 5km Global Products from NOAA Coral Reef Watch. **Remote Sensing** 6(11): 11579-11606, doi:10.3390/rs6111579.

Liu, G., J.L. Rauenzahn, S.F. Heron, C.M. Eakin, W.J. Skirving, T.R.L. Christensen, A.E. Strong, J. Li (2013). NOAA Coral Reef Watch 50km Satellite Sea Surface Temperature-Based Decision Support System for Coral Bleaching Management. **NOAA Technical Report NESDIS 143**. NOAA/NESDIS. College Park, MD. 33pp.

## Program Partners:

